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Experiment 27316: HPA Beampattern Measurements

Sean P. Pecknold
James Theriault

Defence R&D Canada – Atlantic

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DRDC Atlantic TM 2004-004
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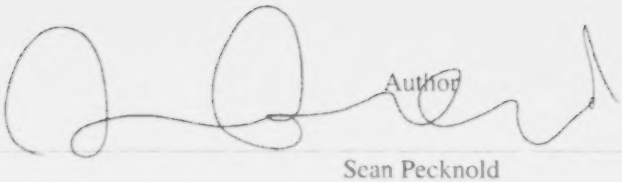

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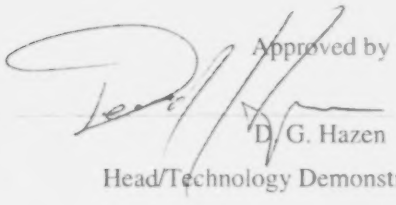

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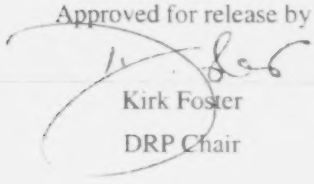

Kirk Foster

DRP Chair

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Abstract

Measurements of the TIAPS horizontal projector array (HPA) beampatterns were performed for three transmit angles: 90° (broadside), 60°, and 45°. The measurements of beampattern for these angles yielded peaks at or near the transmit angle and sidelobes in the correct positions. However, the difference in level from peak to main sidelobe measured was 8-9 dB in all cases, significantly less than the 13 dB expected. Additionally, in the case of the 45° and 60° transmit angles, there appeared to be a double peak, or possibly a very wide (~25°) mainlobe, indicating problems either with the HPA beamforming or possibly an inability of the experiment and analysis to properly separate the direct arrival of the test pings from the surface reflection.

Résumé

Des mesures des diagrammes de faisceau du réseau de projecteurs horizontaux (HPA) du sonar actif-passif intégré remorqué (TIAPS) ont été effectuées pour trois angles d'émission : 90° (transversal), 60° et 45°. Les mesures du diagramme de faisceau pour ces angles d'émission ont produit des crêtes à l'angle d'émission et aux lobes latéraux, ou près de ceux-ci, dans les positions correctes. Toutefois, la différence de niveau entre la crête et le lobe latéral principal qui a été mesurée était de 8-9 dB dans tout les cas, soit sensiblement moins que les 13 dB prévus. En outre, dans le cas des angles d'émission de 45° et de 60°, il semblait y avoir une double crête, ou peut-être un lobe principal très large (~25°), ce qui indique soit que des problèmes se sont posés dans la conformation du faisceau du HPA , soit que l'expérience et l'analyse n'ont pas permis de séparer correctement l'arrivée directe des impulsions d'essai et la réflexion à la surface.

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Executive summary

Introduction

TIAPS, the Towed Integrate Active-Passive Sonar, is a Technology Demonstration project designed to explore the potential development of a next-generation sonar system. One of the objectives of the TIAPS project is to provide a low-frequency active source integrated into the TIAPS active and passive receive array system. Two low-frequency active sources were developed and tested. One of these, the VP2, is a separately towed vertical array of two free-flooding ring projectors with an azimuthally omnidirectional beampattern. The second, the HPA (Horizontal Projector Array), is a 32 element array of barrel stave projectors that can be towed using the same tow cable as the receive arrays, and which requires (and allows) the selection of a transmit angle in azimuth.

Experimental Design

This experiment was designed to measure the beampatterns of the TIAPS horizontal projector array (HPA). Beampattern measurements were performed using three transmit angles: 90° (broadside), 60° and 45°. The UAT (Underwater Acoustic Target) and a GPS-equipped sonobuoy were used for recording, and two runs at each transmit angle were done.

Results

The measurements of beampattern for the broadside, 60° and 45° transmit angles yielded peaks at or near the transmit angle and sidelobes in the correct positions. However, the difference in level from peak to sidelobe measured was 8-9 dB in both cases, significantly less than the 13 dB expected. Additionally, in the case of the 45° and 60° transmit angles, there appeared to be a double peak, or possibly a very wide (~25°) mainlobe. This points to either a problem in the HPA beamforming or possibly problems caused by interaction of the working barrel staves with the non-functional ones.

Future plans

Additional opportunities for measurement of HPA beampatterns as part of the TIAPS project are not anticipated.

Sean P. Pecknold and James Theriault. 2004. Experiment 27316: HPA Beampattern Measurements. DRDC Atlantic TM 2004-004. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Le TIAPS, le sonar remorqué intégré actif et passif, s'inscrit dans le cadre d'un projet de démonstration de la technologie conçu pour explorer le développement potentiel d'un système sonar de la prochaine génération. L'un de ses objectifs consiste à fournir une source active basse fréquence intégrée au réseau de réception actif et passif du TIAPS. Deux sources actives basse fréquence ont été développées et mises à l'essai. L'une d'elles, le VP2, est un réseau vertical remorqué séparé composé de deux projecteurs annulaires à inondation libre présentant un diagramme de faisceau omnidirectif en azimut. La seconde, le HPA (réseau de projecteurs horizontaux), est un réseau de projecteurs à douves composé de 32 éléments, qui peut être remorqué au moyen du même câble de remorquage que les réseaux de réception et qui exige (et permet) la sélection d'un angle d'émission en azimut.

Conception de l'expérience

Cette expérience visait à mesurer les diagrammes de faisceau du réseau de projecteurs horizontaux (HPA) du TIAPS. Des mesures des diagrammes de faisceau ont été effectuées pour trois angles d'émission : 90° (transversal), 60° et 45°. L'UAT (objectif acoustique sous-marin) et une bouée acoustique avec GPS ont été utilisés pour l'enregistrement, et deux séries de mesures ont été effectuées à chaque angle d'émission.

Résultats

Les mesures du diagramme de faisceau pour des angles d'émission de 90°, 60° et de 45° ont produit des crêtes à l'angle d'émission et aux lobes latéraux, ou près de ceux-ci, dans les positions correctes. Toutefois, la différence de niveau entre la crête et le lobe latéral principal qui a été mesurée était de 8-9 dB dans les deux cas, soit sensiblement moins que les 13 dB prévus. En outre, dans le cas des angles d'émission de 45° et de 60°, il semblait y avoir une double crête, ou peut-être un lobe principal très large (~25°), ce qui indique ou bien un problème dans la conformation de faisceau HPA ou peut-être des problèmes dus à l'interaction des douves opérationnelles avec les douves non fonctionnelles.

Recherches futures

On ne prévoit pas d'autres occasions d'effectuer des mesures des diagrammes de faisceau du HPA dans le cadre du projet TIAPS.

Sean P. Pecknold et James Theriault. 2004. Experiment 27316: HPA Beampattern Measurements. [Expérience 27316 : Mesures des diagrammes de faisceau du HPA] RDDC Atlantique TM 2004-004, R & D pour la défense Canada – Atlantique.

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1. Experimental setup

1.1 Planned setup

The objective of experiment 27316 was the measurement of the beampatterns of the TIAPS horizontal projector array (HPA). This is an array consisting of 32 barrel-stave projectors in a horizontal towed array, with element spacing of 0.555 m. Further details concerning the HPA system and its development can be found in [1]. The planned experimental setup consisted of using the HPA to transmit HFMs with a 5 second repetition rate. The UAT would be used to receive, to permit both an accurate GPS fix and to allow sufficient dynamic range for measurement of the beampattern across a wide range of angles. The HPA was to be used at a depth of 70 m (the initial setup called for the HPA to be towed at the same depth as the UAT), with the UAT deployed at 120 m. A bandwidth of 240 Hz is used with a 0.25 second pulse length to allow for adequate resolution of the paths across a good sampling of the beampattern angle. Figure 1 indicates the path difference between the direct and surface reflected paths in milliseconds versus the time from CPA (closest point of approach) between projector and receiver, based on a ship speed of 4 knots, a CPA of 190 m and the given deployment depths.

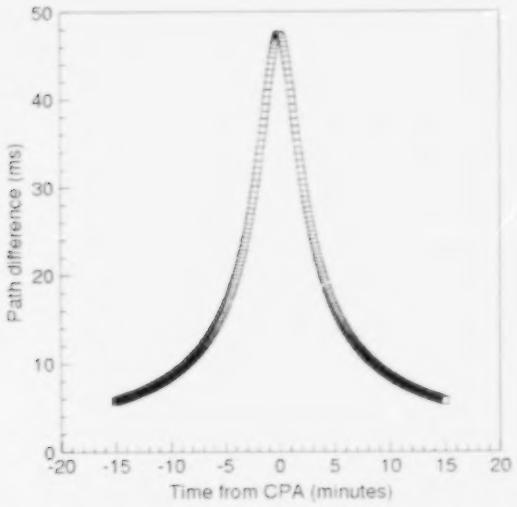

Figure 1. *Path difference vs. time from CPA*

Figure 2 shows the sampled transmit angle versus the time from CPA. Given the pulse length and bandwidth, it was calculated that a path difference of 17 ms could be distinguished. This translated to 5 minutes before and after CPA (from Figure 1) or the ability to sample transmit angles from 20° to 160° (from Figure 2).

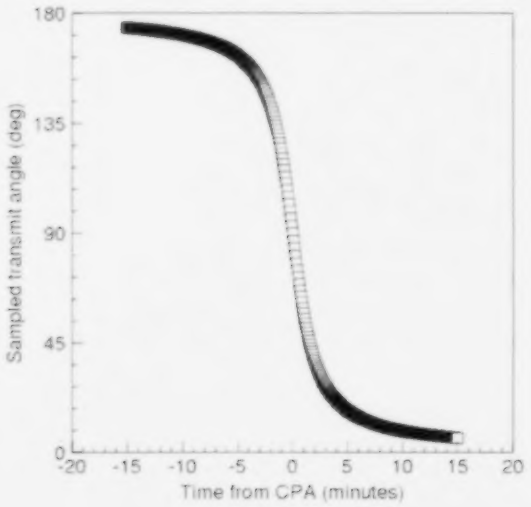

Figure 2. *Sampled transmit angle vs. time from CPA*

1.2 Experiment description

The experiment took place April 14, 2003. The final setup was as follows:

The source used was the HPA. Only 27 elements were usable in this experiment. Channels 7, 10, 18, 23 and 26 were disabled. Transmit was at 6dB down with a nominal source level of 209dB. Beamsteer is measured from 0° at aft endfire. The transmit waveforms were:

1. At a beamsteer of 90°, a 0.25 second HFM with bandwidth 240 Hz and centre frequency 1140 Hz. This run was then repeated.

2. At a beamsteer of 60°, a 0.25 second HFM with bandwidth 240 Hz and centre frequency 1140 Hz. This run was then repeated.

3. At a beamsteer of 45°, a 0.25 second HFM with bandwidth 200 Hz and centre frequency 1120 Hz. This run was then repeated.

A uniform (spatial) shading was employed for the HPA elements.

The UAT was deployed as a receiver at a depth of 120 m, but was unavailable until partway through the first run. A GPS sonobuoy was also deployed at a depth of 120 m.

The sound speed at the HPA depth was measured to be approximately 1525 m/s.

An experimental log indicating ship speed and depth follows.

> 12:13. The HPA was at a depth of 70 m. The UAT was unavailable, so a GPS sonobuoy was used at a depth of 120 m. CPA at 1 cable (190 m) will be performed.
>
> 12:47. The UAT became available partway through the first run, and CPA will be performed on both UAT and the sonobuoy for the remainder of the experiment.
>
> 13:20. Beginning pinging, second run 90° beamsteer. HPA has come up to 51 m depth. CPA will be on UAT, distance near 1 cable.
>
> 13:54. Stopped pinging, turning for 60° beamsteer run.
>
> 14:07. Out of turn, pinging 60° beamsteer.
>
> 14:18. HPA depth up to 43 m (from 53 at beginning of run). Speed 4.8 kts.
>
> 14:23. Pings stopped, turning about.
>
> 14:45. Beginning pinging, second run 60° beamsteer. Speed 4.1 kts, HPA depth 53 m.
>
> 15:03. Stopped pinging.
>
> 15:28. Beginning pinging, first run 45° beamsteer. Speed 6.0 kts, HPA depth 33 m.
>
> 15:32. Speed slowed to 5 knots, depth 45 m.
>
> 15:34. Speed slowed to 4.5 knots, depth 48m.
>
> 15:37. CPA 200m UAT w. ship.
>
> 15:48. Stopped pinging.
>
> 16:07. Beginning pinging, second run 45° beamsteer. Speed 3.8 kts, HPA depth 57 m.
>
> 16:17. CPA sonobuoy.

Figure 3 indicates locations for the HPA (derived from ship GPS) and for the UAT and sonobuoy from each of their GPS sensors. These locations are only plotted for the actual runs.

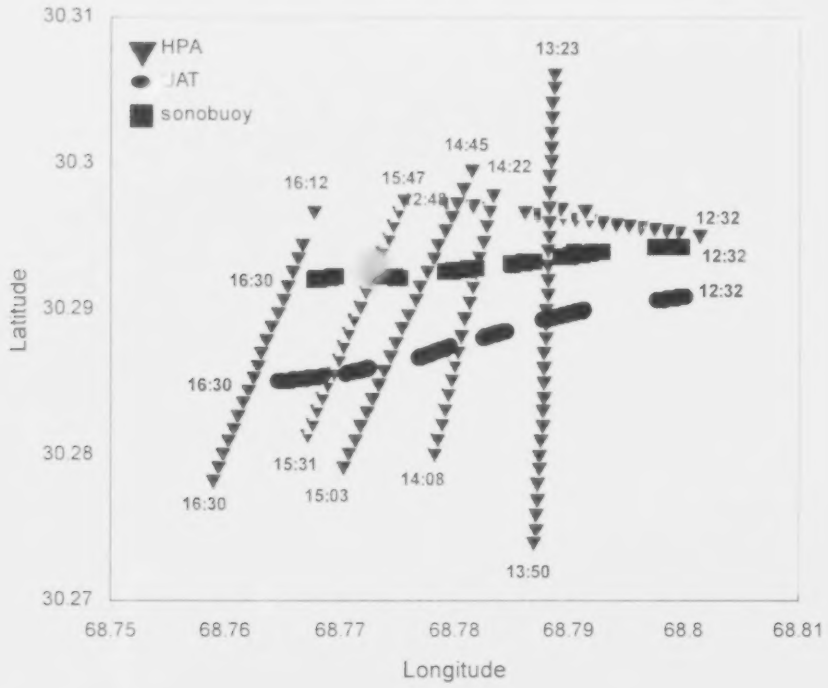

Figure 3. *HPA, UAT and sonobuoy positions.*

For the analysis of the HPA beamforming, these positions were then transformed to range and transmit angle. The range and transmit angles from the HPA to the UAT are shown in Figure 4, those from the HPA to the sonobuoy in Figure 5. Due to the lower dynamic range of the GPS sonobuoy [2], usable pings could only be extracted from runs 1 and 2.

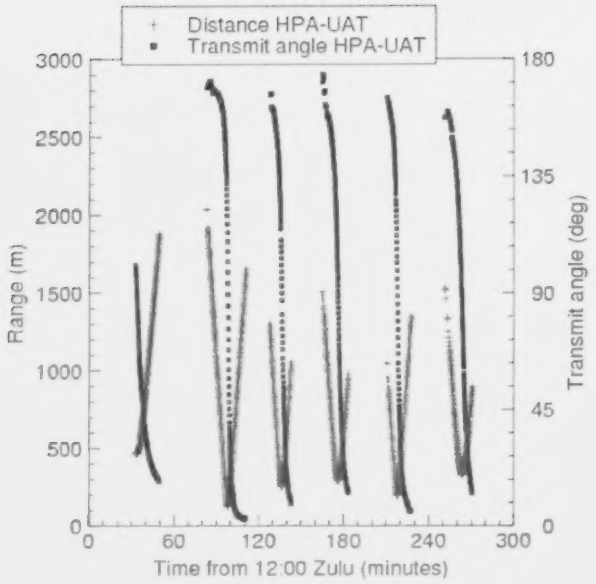

Figure 4. *Range and transmit angle from HPA to UAT.*

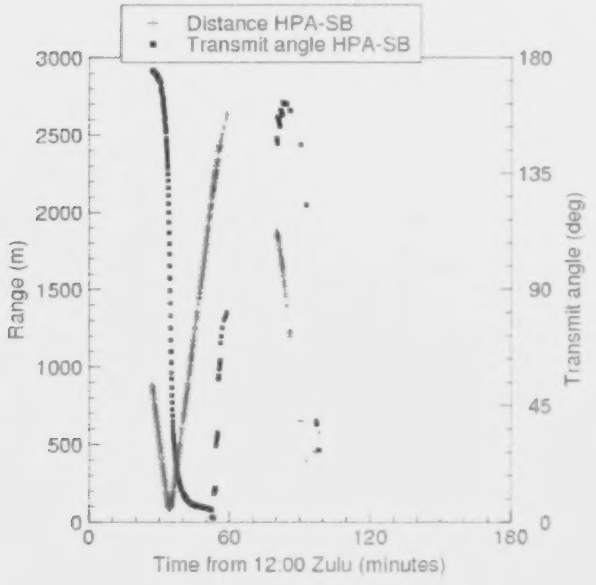

Figure 5. *Range and transmit angle from HPA to sonobuoy.*

2. Results

2.1 UAT data

The time-series data from channel 0 of the UAT were collected. An example of the data is shown in Figure 6.

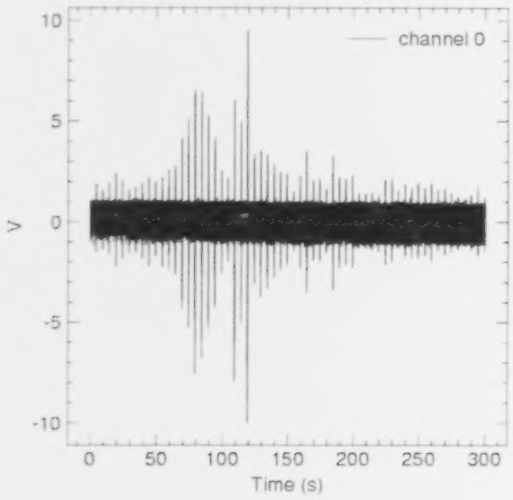

Figure 6. *Time series data from UAT channel 0.*

The time-series was matched-filtered in the time domain using an IDL routine for correlation with waveforms as given in section 1.2. Another IDL routine, PROC_PING [3] was used to find the peaks in the received level (*RL*). An example of the output of PROC_PING is shown in Figure 7.

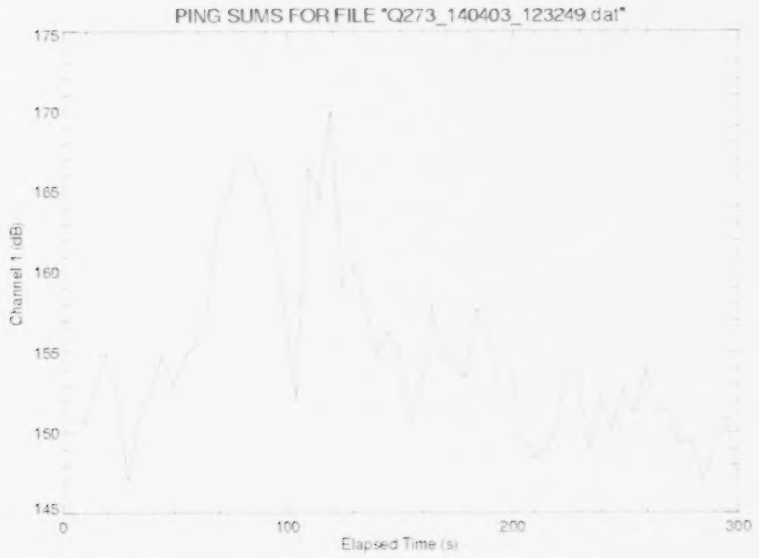

Figure 7. *Output from PROC_PING for UAT channel 0 (listed as channel 1, i.e. first channel, on plot).*

The beampattern (BP), was calculated from the received levels (RL) and source level (SL) and adjusted for spherical spreading based on the range, r:

$$BP = RL - SL + 20\log_{10} r$$

This beampattern was then plotted against β, the transmit angle, as calculated from GPS measurements of both the UAT and CFAV Quest. This calculation was done using the IDL program BETA_TX [3]. The cable scope could not be measured exactly, due to a problem with the equipment. The distance from the CFAV Quest GPS receiver to the centre of the HPA was estimated as 180 m, including distance on ship, length of the HPA, and cable scope. Plots of the beampattern for each run are overlaid on the theoretical beampattern (taking into account the missing channels) at the transmit centre frequency in Figures 8 through 10.

The exact positioning of the main lobe and its level versus the sidelobes is very dependent on the measurement of range and bearing angle. Given that the knowledge of the position of the HPA and UAT (and sonobuoy) are estimates, a measurement of the performance of the HPA is necessarily also an estimate.

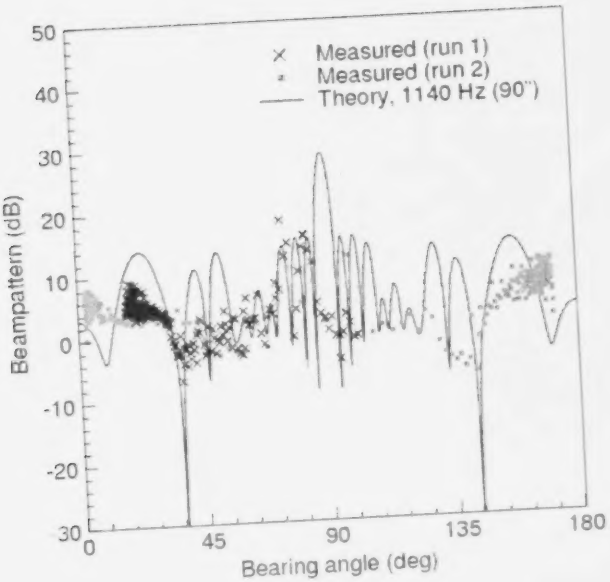

Figure 8. *Measured versus theoretical beampattern for HPA with broadside (90°) transmit (runs 1 and 2).*

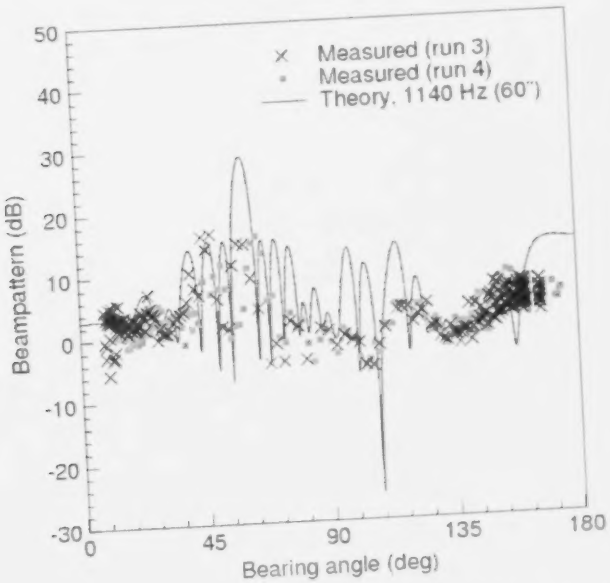

Figure 9. *Measured versus theoretical beampattern for HPA with 60° transmit angle (runs 3 and 4).*

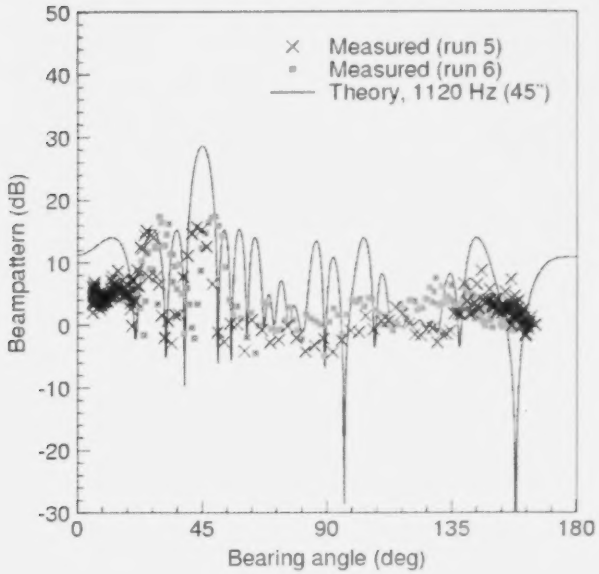

Figure 10. *Measured versus theoretical beampattern for HPA with 45° transmit angle (runs 5 and 6).*

The peaks of the measured beampatterns appear to correspond roughly to the theoretical peaks in position (i.e. bearing angle) for the 45° transmit angle, with the peak values for runs 5 and 6 at 48° and 40° respectively, and for run 4 at the 60° transmit angle, with a peak at 62°. Run 3 of the 60° transmit angle has its peak at 46°, but both the 45° and 60° transmits seem to have two main lobes, slightly offset from each other on the 60° case. In the broadside steering case, the peak seems to be at approximately 80°, and it is not obvious that there are two lobes.

The sidelobes appear somewhat different for each transmit angle. In particular, the (theoretical) peaks near 135° in the broadside, the peaks near 110° and forward endfire for the 60° transmit angle, and the sidelobe structure for most of the 45° transmit angle appear different from what is observed. Part of this may be due to the fact that the pulse used was wideband and the sidelobes are frequency dependent. In addition, the height of the peaks is anywhere from 8 dB to 10 dB above the level of the highest sidelobes, significantly less than the 13 dB predicted theoretically. These observations may indicate that the transmit delays used in beamsteering are not correct or that they are not being correctly implemented. Another possible source of error is a failure in omnidirectionality of the barrel staves due to interaction between the working barrel staves and the non-functional elements (this was noted as a possibility during experiment Q264 [4]).

Figures 11-13 show the measured beampatterns versus an averaged theoretical beampattern across the bandwidth of the transmitted signal. Here we see that the sidelobe structure appears to correspond more closely to the measured values, particularly for the near-endfire sidelobes in the 60° transmit angle case.

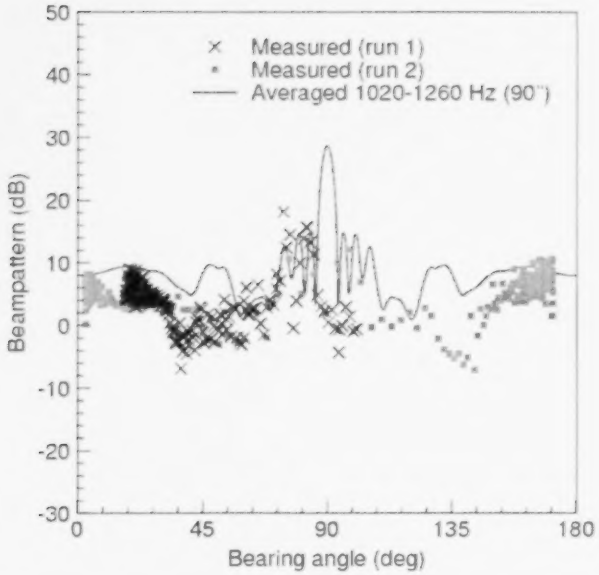

Figure 11. *Measured versus theoretical averaged beampattern for HPA, 90° transmit (runs 1 and 2).*

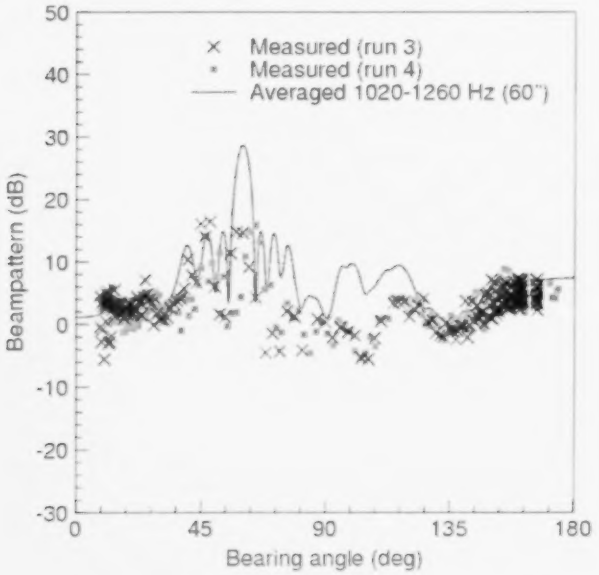

Figure 12. *Measured versus theoretical averaged beampattern for HPA, 60° transmit (runs 3 and 4).*

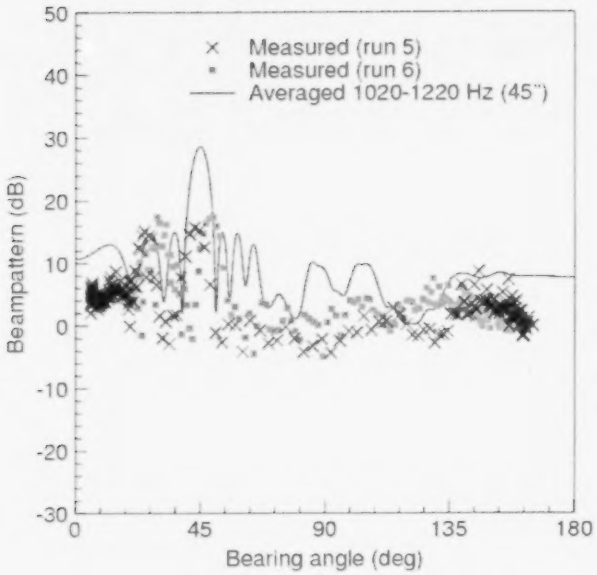

Figure 13. *Measured versus theoretical averaged beampattern for HPA 45° transmit (runs 5 and 6).*

2.2 Sonobuoy Data

As mentioned in Section 1.2, the data from the sonobuoy was only usable for run 1 and a part of run 2. For the remaining runs, the signal to noise ratio was insufficient for an estimate of the beampattern. The same procedure was followed for these runs as in Section 2.1 for the UAT data, with the results plotted in Figure 14 together with the results from the UAT data for the first two runs and the theoretical beampattern.

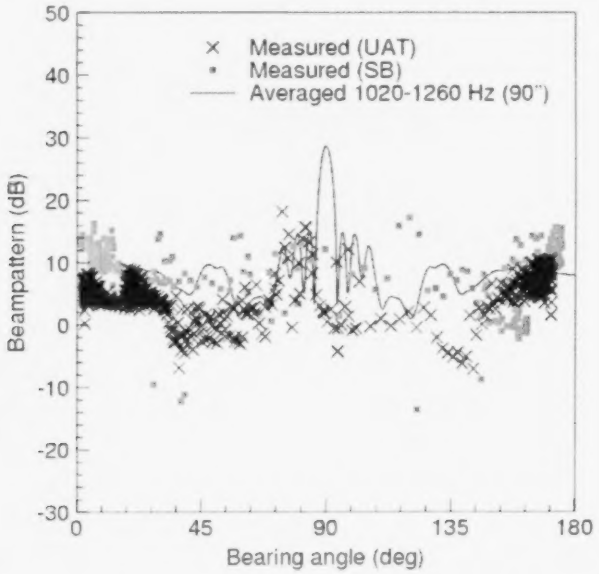

Figure 14. *Measured versus theoretical averaged beampattern for HPA, 90° transmit angle for UAT and sonobuoy receivers.*

It is evident that the sonobuoy data has several peaks at approximately 10°, 30°, 60°, 130° and 170°. Given that these peaks all appear to be within 2-3 dB of each other, they do not provide any evidence that the HPA beampattern is being produced in accordance with the theory.

3. Conclusions

This experiment was designed to measure the beampatterns of the TIAPS horizontal projector array. In order to measure these beampatterns, there was a requirement that the direct path of each ping be distinguishable from the surface reflected path. This created the constraint that both the HPA and the receiver be as deep as possible. Unfortunately, because the HPA was unable to achieve the required depth, the source and receiver were located at different depths, so that the receiver never lay within the broadside beam of the HPA. The lack of sampling of transmit angle near broadside did not allow for an adequate measurement of the broadside beampattern. The measurements of beampattern for both a 60° and 45° transmit angle yielded peaks at or near the transmit angle and sidelobes in the correct positions. However, the difference in level from peak to sidelobe measured was 8-9 dB in both cases, significantly less than the 13 dB expected. Additionally, in the case of the 45° and 60° transmit angles, there appeared to be a double peak, or possibly a very wide (~25°) mainlobe. This points to either a problem in the HPA beamforming or possibly problems caused by interaction of the working barrel staves with the non-functional ones.

4. References

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List of symbols/abbreviations/acronyms/initialisms

CPA	Closest point of approach
DND	Department of National Defence
GPS	Global Positioning System
HFM	Hyberbolic Frequency Modulated
HPA	Horizontal Projector Array
TIAPS	Towed Integrated Active Passive Sonar
UAT	Underwater Acoustic Target

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Measurements of the TIAPS horizontal projector array (HPA) beampatterns were performed for three transmit angles: 90° (broadside), 60°, and 45°. The mainlobe of the broadside transmit could not be measured due to inadequate sampling of the transmit angle. The measurements of beampattern for both a 60° and 45° transmit angle yielded peaks at the transmit angle and sidelobes in the correct positions. However, the difference in level from peak to main sidelobe measured was 8-9 dB in both cases, significantly less than the 13 dB expected. Additionally, in the case of the 45° and 60° transmit angles, there appeared to be a double peak, or possibly a very wide (~25°) mainlobe, indicating problems either with the HPA beamforming or possibly an inability of the experiment and analysis to properly separate the direct arrival of the test pings from the surface reflection.

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Beampatterns, horizontal projector arrays